

Title: Radiolabelled phenylethyl imidazole carboxylic acid ester derivatives

Field of Invention: Adrenal scintigraphy for detection of adrenal cortical pathology

#### Summary of Invention

The invention relates to radioactively labelled derivatives of (*R*)-3-(1-phenylethyl)-3*H*-imidazole-4-carboxylic acid esters and methods for preparing these compounds. The invention also relates to the use of these radioactively labelled compounds as radiopharmaceuticals. In particular, these compounds bind selectively to adrenocortical tissue facilitating the diagnosis of adrenal cortical masses such as incidentaloma, adenoma, primary and metastatic cortical carcinoma.

#### Background of Invention

The present invention relates to a class of substituted (*R*)-3-(1-phenylethyl)-3*H*-imidazole-4-carboxylic acid esters which interact selectively with the mitochondrial cytochrome P-450 species in the adrenal cortex (Vanden Bossche, 1984). When labelled with radiohalogen (iodine-123; bromine-76; fluorine-18 and others) these compounds serve as radiotracers for the diagnosis of adrenal cortical masses such as incidentalomas, adenomas, primary and metastatic cortical carcinoma. When labelled with a beta-emitting radionuclide (iodine-131; bromine-82), these radiotracers may be used for radionuclide therapy. The main application is for tumour diagnosis (Khan 2003).

In particular, the compounds according to this invention are potent inhibitors of steroid P450  $\beta$  hydroxylation and bind with high affinity to adrenocortical membranes. In fact, the compounds in accordance with this invention have been found to possess an almost 1000-fold selective affinity when compared with known, clinically used inhibitors (metyrapone, ketoconazole). Therefore, when injected intravenously, the labelled derivatives of the present invention, accumulate rapidly in the adrenals, reaching radioactivity levels that are diagnostically useful.

The parent compound etomidate (ethyl ester; ETO) is clinically used as a short-acting hypnotic drug. When incubated with human adrenocortical tissue slices, it was

shown to block the conversion of 11-deoxycortisol to cortisol and of 11-deoxycorticosterone (DOC) to corticosterone and aldosterone (Weber 1993; Engelhardt 1994). Also metomidate (MTO), the methyl ester, is an equally potent inhibitor of steroid 11 $\beta$ -hydroxylation. (R)-configuration of the methyl substituent at the chiral C-atom is essential for enzyme inhibition (Vanden Bossche, 1984).

Clinical findings with the radiotracer [O-methyl-<sup>11</sup>C]metomidate have indicated high uptake in lesions of adrenocortical origin, including adenomas, but very low uptake in lesions of non-adrenocortical origin (Bergström 1998; 2000). Specific uptake has been reported in multiple metastases in the lung of a primary adrenocortical carcinoma (Mitterhauser 2002). However, the differentiation between benign (e.g., adenoma) and malignant (e.g., carcinoma) is primarily based on the size and shape of the lesion; irregularities in tumour uptake and multiple lesions are an indication of malignancy (Khan 2003).

Although <sup>11</sup>C-metomidate has “ideal” biological characteristics for scintigraphy of the adrenals and tumor derived therefrom, application of the radiopharmaceutical is limited to hospitals with a PET facility. <sup>11</sup>C is a cyclotron product and decays with a half-life of 20 min, therefore, <sup>11</sup>C-metomidate must be synthesized immediately prior to use.

Halogenations, on the other hand, offer sufficient flexibility, time for preparation and shipment. (Iodine-123 T<sub>1/2</sub> = 13.2 hours; Br-76 T<sub>1/2</sub> = 16 hours).

Enzyme inhibitors, such as metyrapone have been labelled with radioiodine for adrenal scintigraphy, however, these compounds have never been used for clinical diagnosis (Wieland, 1982; Robien & Zolle, 1983). A comparison of the binding affinities (IC<sub>50</sub>-values) of known inhibitors with etomidate clearly demonstrated the higher potency of etomidate and metomidate.

The available radiotracers for imaging the adrenal cortex and adrenal cortex-derived tumors are labelled cholesterol derivatives. These include 6 $\beta$ -[<sup>131</sup>I]-iodomethyl-19-norcholesterol (NP-59) (Basmadjian, 1975) and 6 $\beta$ -[<sup>75</sup>Se]-selenomethyl-19-norcholesterol (Scintadren™) (Sakar, 1976). Both NP-59 and Scintadren™

accumulate in the adrenals slowly, within days, requiring long-lived radionuclides as a label (Iodine-131  $T_{1/2}$  = 8.04 days; Selen-75  $T_{1/2}$  = 120 days). Iodine-131 is also emitting beta-radiation, which contributes considerably to the radiation exposure. The diagnostic use of beta-emitters is no longer state of the art.

In view of the drawbacks of above mentioned agents with respect to patient care (high radiation exposure, repeated imaging procedures), the development of radiolabeled derivatives of etomidate and metomidate would greatly improve radionuclide imaging procedures for the detection and follow-up of adrenal disease.

The invention disclosed herein concerns radiotracers with high selectivity and rapid uptake kinetics, providing metomidate labelled with a SPECT or PET radionuclide with a short physical half-life.  $^{123}\text{I}$ -MTO offers optimal imaging characteristics with SPECT, with high accumulation of the radiotracer in the adrenals, so that imaging may be started 10-15 minutes post injection of the radioactive dose. Radiation exposure to the patient is minimized.

#### Detailed Description of the Drawings

Figure 1 summarizes the relevant characteristics of radioiodinated metomidate binding to adrenal membranes.

Figure 2 provides the  $\text{IC}_{50}$  of various etomidate derivatives as inhibitors of the binding of radioiodinated metomidate.

Figure 3 describes the accumulation of radioiodinated metomidate in different organs *in vivo*, after up to 120 minutes post-injection.

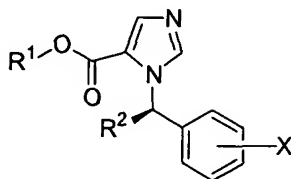
Figure 4 provides the target:non-target ratios of radioiodinated metomidate after different time intervals post-injection.

Figure 5 provides the results of experiments describing the *in vivo* distribution of radiofluorinated etomidate.

## Detailed Description of the Invention

The present invention provides a compound of formula I,

(I)



wherein

**R<sup>1</sup>** represents a straight or branched alkyl chain containing from 1 to 4 carbon atoms, wherein the alkyl group is optionally substituted with a halogen;

**R<sup>2</sup>** represents a straight alkyl chain in (R)-configuration containing from 1 to 2 carbon atoms;

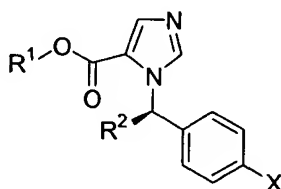
**X** denotes a halogen or a radiohalogen;

As used herein, the expression "alkyl," includes methyl and ethyl groups, and straight-chained or branched propyl groups. Particular alkyl groups are methyl, ethyl, 2-fluoroethyl, n-propyl, and isopropyl, especially methyl and ethyl.

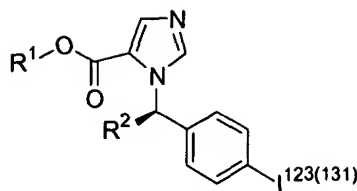
The term "halogen" as used herein, includes iodine, bromine and fluorine, especially iodine.

The compound of formula (I) in accordance with the present invention is suitably a halogenated derivative of formula **IA**, and a radiolabelled derivative of formula **IB**:

(IA)



(IB)



wherein

**R**<sup>1</sup> and **R**<sup>2</sup> are as defined above;

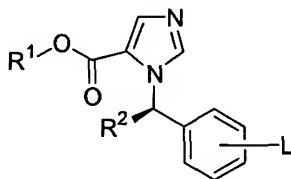
**X** denotes a halogen resp. radioiodine;

Preferred are compounds of formula (IB), wherein **R**<sup>1</sup> and **R**<sup>2</sup> is methyl and **X** is <sup>123</sup>I or <sup>131</sup>I, namely (*R*)-3-[1-(4-[<sup>123</sup>I]iodophenyl)ethyl]-3*H*-imidazole-4-carboxylic acid methyl ester (<sup>123</sup>I-MTO) and (*R*)-3-[1-(4-[<sup>131</sup>I]iodophenyl)ethyl]-3*H*-imidazole-4-carboxylic acid methyl ester (<sup>131</sup>I-MTO); and

wherein **R**<sup>1</sup> is ethyl, **R**<sup>2</sup> is methyl and **X** is <sup>123</sup>I or <sup>131</sup>I, namely (*R*)-3-[1-(4-[<sup>123</sup>I]iodophenyl)ethyl]-3*H*-imidazole-4-carboxylic acid ethyl ester (<sup>123</sup>I-ETO) and (*R*)-3-[1-(4-[<sup>131</sup>I]iodophenyl)ethyl]-3*H*-imidazole-4-carboxylic acid ethyl ester (<sup>131</sup>I-ETO).

The present invention includes within its scope stannylated derivatives of formula II:

(II)

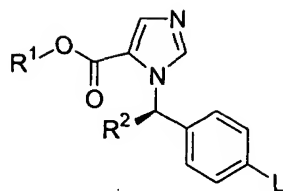


wherein **R**<sup>1</sup> and **R**<sup>2</sup> are as defined above;

**L** represents a trimethyl-, triethyl-, tri-*n*-propyl- and a tri-*n*-butylstannyl group.

The stannylated precursors are prepared from the respective halogenated compounds of formula IA to give IIA:

(IIA)



wherein **R**<sup>1</sup> and **R**<sup>2</sup> are as defined above;

**L** represents a trimethyl-, triethyl-, tri-*n*-propyl- and a tri-*n*-butylstannyl group.

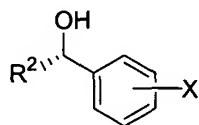
Compounds of formula **II** contain a leaving group **L**, suitably selected from trimethylstannyl, triethylstannyl, tri-*n*-propylstannyl and tri-*n*-butylstannyl, especially trimethylstannyl.

Compounds of formula **IIA** are key intermediates for radiotracer synthesis by oxidative radiohalogenido destannylation. The trialkylstannyl groups in an aromatic ring can be replaced easily by radiohalogen to yield the respective radioactively labelled compounds of formula (IB).

The invention concerns a process of synthesizing compounds of formula (I) by a stereoselective and regioselective new approach.

The compounds according to the invention may be prepared by a process which comprises coupling a compound of formula **III**:

(III)



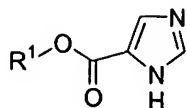
wherein

**R**<sup>2</sup> represents a straight alkyl chain in (*S*)-configuration containing from 1 to 2 carbon atoms;

**X** represents a halogen;

with a compound of formula IV:

(IV)

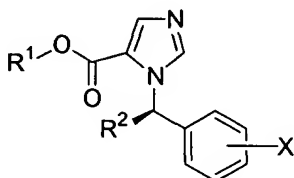


wherein

**R<sup>1</sup>** represents a straight or branched alkyl chain containing from 1 to 4 carbon atoms, wherein the alkyl group is optionally substituted with a halogen;

The reaction between compounds **III** and **IV** proceeds with inversion of configuration, to give compounds of formula **I**:

(I)



wherein

**R<sup>1</sup>** represents a straight or branched alkyl chain containing from 1 to 4 carbon atoms;

**R<sup>2</sup>** represents a straight alkyl chain in (*R*)-configuration containing from 1 to 2 carbon atoms;

**X** represents a halogen;

Particular alkyl groups are methyl, ethyl, 2-fluoroethyl, n-propyl, and isopropyl, especially methyl and ethyl.

The reaction between compounds **III** and **IV** is based on the known Mitsunobu reaction (Mitsunobu, 1981). The alcohol (*S*)-1-(4-iodophenyl)ethanol (**III**) is reacted with methyl imidazole-4-carboxylate (**IV**) in the presence of triphenylphosphane and a dialkyl azodicarboxylate (preferably di-*t*-butyl azodicarboxylate). Triphenyl

phosphinoyl and the hydrazo ester are by-products of the reaction. The reaction conditions favour activation of the alcohol to generate the reactive alkoxyphosphonium salt. Methyl imidazole-4-carboxylate is expected to be deprotonated, thus *N*-1 and *N*-3 could react as nucleophile with the alkoxyphosphonium cation to give a mixture of two isomeric *N*-substituted imidazoles. Yet, when coupling III and IV at low temperature, alkylation is observed exclusively at *N*-3 with clean inversion.

Previous attempts to react secondary alcohols (alkylaryl or diaryl carbinols) with symmetrical imidazole-4,5-dinitrile produced partial resp. complete racemization by the Mitsunobu reaction (Botta et al., 1994; Corelli et al., 1995).

(*S*)-III is a key intermediate and needs to be synthesized; methyl imidazole-4-carboxylate IV is commercially available.

Since not commercially available, the starting material of formula III is prepared by a novel synthetic approach, described hereafter and in scheme 1:

Starting from 4-iodophenyl methyl ketone, which is reduced to the racemic alcohol and converted to ( $\pm$ )-1-(4-iodophenyl)ethyl chloroacetate, the racemic ester is subjected to stereoselective enzyme hydrolysis. The remaining (*S*)-isomer of the ester is separated from the (*R*)-alcohol and transesterified to give (*S*)-1-(4-iodophenyl)ethanol (ee >98%) III.

Laumen & Schneider (1988) reported that lipase SAM II hydrolyses acetates and chloroacetates of secondary benzyl alcohols with high enantioselectivity, therefore, Schneider's procedure is applied to the resolution of racemic 1-(4-iodophenyl)ethanol. Lipase SAM II is known to hydrolyse preferentially the (*R*)-esters of secondary benzyl alcohols; however, application with the substrate described in the invention is new.

(*R*)-4-iodo-metomidate is derived exclusively from the (*S*)-alcohol of the ester which is not accepted as substrate by lipase SAM II. Coupling of (*S*)-1-(4-iodophenyl)ethanol with methyl imidazole-4-carboxylate yields (*R*)-4-iodo-metomidate with clean inversion.



This novel reaction offers a versatile approach to the synthesis of compounds described by formula I. (*S*)-1-(4-iodophenyl)ethanol (ee >98%) **III** is synthesized by lipase-catalysed resolution and coupled with methyl 4-imidazole carboxylate **IV**. The two fragments are joined regioselectively at *N*-3 with clean inversion of configuration producing (*R*)-methyl 3-[1-(4-iodophenyl)ethyl]-3*H*-imidazole-4-carboxylate (4-iodo-MTO) **IA**. Finally, 4-iodo-metomidate is transformed to the 4-trimethylstannyl derivative **IIA** to serve as a precursor for labelling ETO and MTO with radiohalogen **IB**.

Compounds of formula **II** wherein **L** represents a leaving group, may be prepared by standard stannylation techniques. The exchange of X (iodine) for the trialkylstannyl substituent (**L**) is catalysed by tetrakis (triphenylphosphane) palladium to give a stannylated compound of formula **IIA**.

Radiohalogenated compounds of formula **IB** are conveniently prepared by reacting a compound of formula **IIA** with radiohalogen (Iodine-123; iodine-131) in the presence of an oxidizing agent, at room temperature.

The radioligand <sup>131</sup>I-MTO is produced with a specific activity of 1 MBq/nmol, resp. 27.3 µCi/nmol.

The following Examples illustrate the preparation of compounds according to the invention.

The compounds in accordance with the present invention potently and selectively bind to adrenocortical membranes (cytochrome P-450 β-hydroxylase).

#### Radioligand Binding

Whole adrenals from adult male Wistar rats were homogenized in 10 mM K<sub>2</sub>HPO<sub>4</sub>/10 mM HEPES (pH 7.1) with a glass/teflon piston (Potter-type). The homogenate was centrifuged at 35.000 x g for 10 min, the pellet was resuspended in fresh buffer and centrifuged again. Membranes were washed 2 more times and stored as aliquots at –80°C.

### [<sup>131</sup>I]MTO binding procedure

Glass vials containing 0.5 ml of 10 mM K<sub>2</sub>HPO<sub>4</sub>/10 mM HEPES, 150 mM NaCl (pH 7.1), 20,000-40,000 cpm [<sup>131</sup>I]MTO together with 2 nM 4-iodo-MTO as carrier (i.e. 1 pmol/vial, resulting in a specific activity of 9-18 Ci/mmol), and the adrenal membrane suspension corresponding to 0.2 mg tissue/vial, were immersed in a 23 °C water bath for 20-30 min. After incubation, membranes with bound radioligand were isolated by filtration through Whatman GF/B glass fiber filters (presoaked in buffer), followed by 2 x 4 mL washings with buffer, then filters were measured in a gamma-spectrometer.

The association time course of [<sup>131</sup>I]MTO to rat adrenal membranes was evaluated at three ligand concentrations, namely 2 nM, 4 nM, and 11 nM of 4-iodo-MTO, respectively (data pooled from 7 experiments). Computerized curve fitting to the association function  $B(t) = B_0 \cdot [1 + \exp(-v \cdot t)]$  resulted in observable association rate constants of  $v = 0.65 \text{ min}^{-1}$ ,  $1.23 \text{ min}^{-1}$ , and  $1.34 \text{ min}^{-1}$  corresponding to association half-times from 30 to 60 seconds.

For dissociation experiments, membranes were fully equilibrated with 2 nM radioligand, and the dissociation was initiated by the addition of excess unlabelled 4-iodo-MTO and stepwise filtration at 15 sec intervals. Four individual experiments demonstrated fast reversibility of binding and resulted in a dissociation constant of  $b = 0.33 \pm 0.05 \text{ min}^{-1}$  and derived dissociation half-times from 1.8 to 2.4 min.

For saturation studies 2 – 100 nM 4-iodo-MTO carrier was used. See summary in Fig. 1. Saturation analysis of [<sup>131</sup>I]MTO binding to rat adrenal membranes (4 representative experiments) produced 15 linear Eadie-Hofstee plots suggesting a single binding site.  $K_D = 7.4 \pm 2.8 \text{ nM}$  (15);  $B_{\text{max}} = 2.4 \pm 0.4 \text{ pmol/mg tissue}$  (15). Incubation for 30 minutes using 10 mM K<sub>2</sub>HPO<sub>4</sub>/10 mM HEPES, 150 mM NaCl (pH 7.1). 0.2 mg tissue bind ~ 10% of the free ligand (0.1 pmol).

### Displacement of [<sup>131</sup>I]MTO binding (Fig. 2)

Compounds of formula I and derivatives were evaluated as competitive inhibitors of [<sup>131</sup>I]MTO binding. Test compounds were incubated at 0.01 – 100 nM concentrations. Non-specific binding was determined with etomidate (10 μM). The reaction was

initiated by the addition of membrane and was terminated by filtration through Whatman GF/B filters (presoaked in buffer), followed by 2 x 4 mL washings with buffer. The filters containing membranes with bound radioligand were measured in a gamma-spectrometer.

IC<sub>50</sub> values (the molar concentration of compound necessary to inhibit binding by 50%) were determined for each test compound by non-linear, least squares regression analysis, using an iterative curve fitting routine.

The IC<sub>50</sub> values for binding to the cytochrome P-450<sub>11β</sub> enzyme system obtained for derivatives of etomidate resp. metomidate of the accompanying Examples were below 10 nM in each case. Moreover, it was demonstrated that (R)-configuration of the methyl substituent at the chiral C-atom is essential for binding, (S)-configuration is not tolerated (IC<sub>50</sub> = 492 nM); cleavage of the ester results in deactivation, the free acid (ETO-acid) is inactive (IC<sub>50</sub> = 123 μM); modification of the ester by 2-fluoroethyl (FETO) is tolerated without a loss of affinity (IC<sub>50</sub> = 3.0 nM); the ethyl ester (etomidate) shows the highest potency (IC<sub>50</sub> = 1.1 nM); the methyl ester (metomidate; IC<sub>50</sub> = 3.7 nM) and 4-iodo-MTO (IC<sub>50</sub> = 9.0 nM) show similar potencies. Metirapone, a known, clinically used inhibitor, showed micromolar potency (IC<sub>50</sub> = 1.2 μM) when tested in this assay.

#### In vivo evaluation of <sup>131</sup>I-MTO (Fig. 3, 4)

Method: <sup>131</sup>I-MTO was used with a radiochemical purity >99% and a specific activity of 57 GBq/μmol. The radiotracer (0.5-1.1 MBq; 10 - 20 μCi) was injected into the tail vein of rats (female, 180-220 gram). Groups of four rats were sacrificed at specified times up to 24 hours post injection. The organs were excised and weighed, the radioactivity was measured at constant geometry using a gamma-spectrometer with a NaI(Tl)-crystal. The data were expressed as percent of injected dose (ID) per organ and as percent of ID per gram tissue.

Results: <sup>131</sup>I-MTO showed high specific uptake in the adrenals of approximately 10% ID/g tissue with a radioactivity plateau for 2 hours. The radiotracer is eliminated both by hepatobiliary and by renal excretion. Renal activity is attributed to <sup>131</sup>I-ETO-acid, which results from enzymatic cleavage of the methyl ester. The renal activity is

increasing up to 4 hours post injection. Based on calculations of the target-to-non-target-ratios the highest contrast for imaging of the adrenals is observed up to one hour post injection.

Thus, [ $^{131}\text{I}$ ]-I-MTO shows a high potential as radiotracer for the functional imaging of adrenal pathology.

Similar distribution kinetics are demonstrated with  $^{18}\text{F}$ -fluoroetomidate. Fig. 5.

The present invention is described below in more detail in connection with the synthesis of the radiotracer (*R*)-3-[1-(4-[ $^{131}\text{I}$ ]iodophenyl)ethyl]-3*H*-imidazole-4-carboxylic acid methyl ester ( $^{131}\text{I}$ -MTO); The example is given merely for illustrative purposes and shall in no way be understood as a limitation of the scope of the present invention which is given by the patent claims.

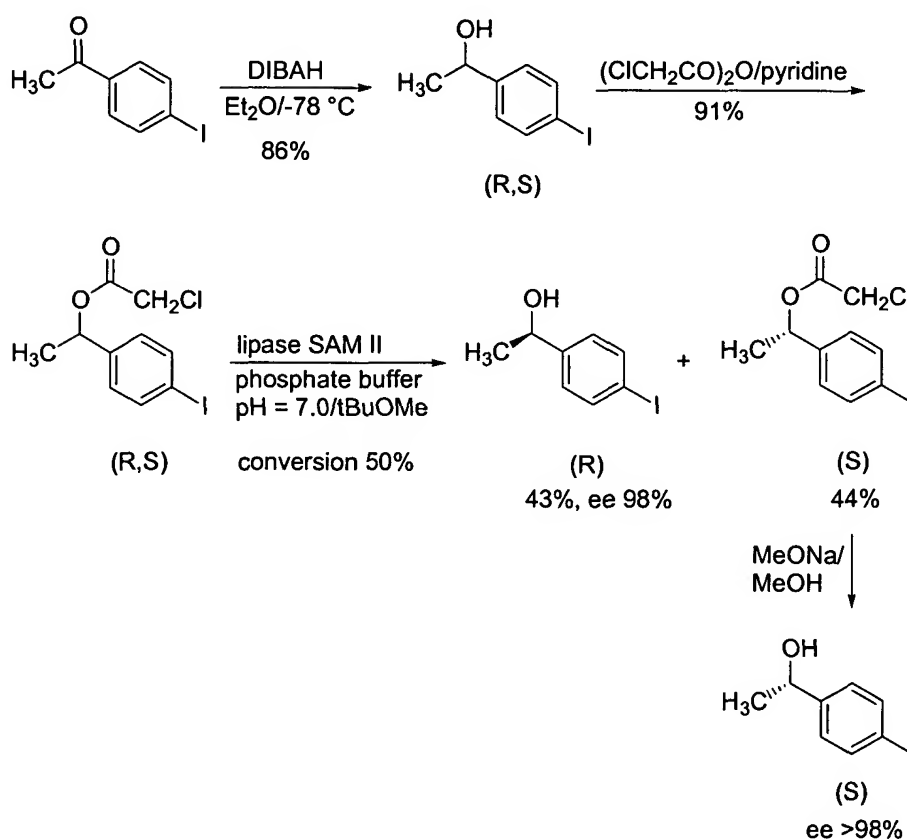
## EXAMPLES

Example 1. Preparation of (*R*)-3-[1-(4-[<sup>131</sup>I]iodophenyl)ethyl]-3*H*-imidazole-4-carboxylic acid methyl ester i.e. (<sup>131</sup>I-MTO);

a. Preparation of (*S*)-1-(4-iodophenyl)ethanol (III)

The substituted (*S*)-alcohol was prepared according to scheme 1

Scheme 1



Preparation of (±)-1-(4-iodophenyl)ethanol

A solution of DIBALH (16.45 cm<sup>3</sup>, 24.67 mmol, 1.5 M solution in toluene) was added dropwise to a stirred mixture of 4-iodoacetophenone (5.08 g, 20.65 mmol) in dry diethyl ether (50 cm<sup>3</sup>) at -78°C in an atmosphere of argon. After stirring for 2 h at -78°C, methanol (2 cm<sup>3</sup>) was added and stirring was continued for 30 min at room

temperature before water (10 cm<sup>3</sup>) was added cautiously. 30 min later, the aluminum hydroxide formed was dissolved in hydrochloric acid (50 cm<sup>3</sup>, 2 M) under cooling with ice. The organic phase was separated, washed with water and a saturated aqueous solution of sodium hydrogen carbonate, dried (magnesium sulphate) and concentrated under reduced pressure. The crude product was purified by flash chromatography (hexane-dichloromethane 1:2; R<sub>f</sub>=0.20) on silica gel and bulb to bulb distillation (0.2 mmHg/90-95°C) to give (±)- (3.91 g, 86%) as liquid which crystallised; mp 47-49°C (lit. 50.5-51.5°C).

δ<sub>H</sub> (400.13 MHz, CDCl<sub>3</sub>) 1.40 (3 H, d, J 6.5, CH<sub>3</sub>CH), 1.75 (1 H, br s, OH), 4.78 (1 H, q, J 6.5, CH<sub>3</sub>CH), 7.06 (2 H, d, J 8.5, 2 x H<sub>arom</sub>), 7.60 (2 H, d, J 8.5, 2 x H<sub>arom</sub>); δ<sub>C</sub> (100.61 MHz, CDCl<sub>3</sub>) 25.62 (CH<sub>3</sub>CH), 70.25 (CH<sub>3</sub>CH), 93.09 (C<sub>arom</sub>), 127.79 (2 C, 2 x HC<sub>arom</sub>), 137.94 (2 C, 2 x HC<sub>arom</sub>), 145.86 (C<sub>arom</sub>).

#### Preparation of (±)-1-(4-Iodophenyl)ethyl chloroacetate

Dry pyridine (6.0 cm<sup>3</sup>) and chloroacetic anhydride (6.2 g, 36.26 mmol) were added to a stirred solution of (±)-1-(4-Iodophenyl)ethanol (5.95 g, 24.0 mmol) in dry dichloromethane (100 cm<sup>3</sup>) at 0°C under an atmosphere of argon. When the reaction was finished (2 h, TLC: hexane-dichloromethane 3:2, R<sub>f</sub> = 0.35 for ester), water (40 cm<sup>3</sup>) and concentrated hydrochloric acid (3.6 cm<sup>3</sup>) were added. After stirring for 10 min, the organic phase was separated and the aqueous phase was extracted with dichloromethane (3 x 15 cm<sup>3</sup>). The combined organic phases were washed with water (50 cm<sup>3</sup>) and a saturated solution of sodium hydrogen carbonate (25 cm<sup>3</sup>), dried (sodium sulfate) and evaporated under reduced pressure. The residue was purified by flash chromatography (hexane-dichloromethane 3:2, R<sub>f</sub> = 0.35) on silica gel and bulb to bulb distillation (0.1 mmHg/105°C) to give chloroacetate (7.09 g, 91%) as a colourless liquid (Found: C, 36.9; H, 3.25, C<sub>10</sub>H<sub>10</sub>ClIO<sub>2</sub> requires C, 37.0; H, 3.1%), which crystallised spontaneously; mp 50-51°C. ν<sub>max</sub> (Si, film)/cm<sup>-1</sup> 2983, 1756, 1591, 1488, 1285, 1176, 1063, 1007; δ<sub>H</sub> (400.13 MHz, CDCl<sub>3</sub>) 1.54 (3 H, d, J 7.0, CH<sub>3</sub>CH), 4.03 (2 H, d, J 14.8, CH<sub>2</sub>Cl), 5.90 (1 H, q, J 7.0, CH<sub>3</sub>CH), 7.08 (2 H, d, J 8.5, 2 x H<sub>arom</sub>), 7.68 (2 H, d, J 8.0, 2 x H<sub>arom</sub>); δ<sub>C</sub> (100.61 MHz, CDCl<sub>3</sub>) 21.84 (CH<sub>3</sub>CH), 40.99 (CH<sub>2</sub>Cl), 73.84 (CH<sub>3</sub>CH), 93.85 (C<sub>arom</sub>), 128.08 (2 C, 2 x HC<sub>arom</sub>), 137.75 (2 C, 2 x HC<sub>arom</sub>), 140.30 (C<sub>arom</sub>), 166.45 (CO).

b. Enzymatic hydrolysis of (±)-1-(4-iodophenyl)ethyl chloroacetate

Racemic chloroacetate (0.835 g, 2.57 mmol) t-butyl methyl ether (4 cm<sup>3</sup>) and phosphate buffer (50 mmol, sterile, 17 cm<sup>3</sup>) and lipase SAM II (96 mg) were stirred vigorously at room temperature. The pH was kept constant at 7.0 by addition of 0.5 N sodium hydroxide using an autotitrator.

98% of the calculated amount of base were consumed in 2.6 hr. The reaction was stopped after another 14 h (virtually no base was consumed during the last 9 hr) by bringing the pH to about 2.0 using 2 N hydrochloric acid. Water (100 cm<sup>3</sup>) was added and ester and alcohol were extracted with dichloromethane (3 x 200 cm<sup>3</sup>). The combined organic layers were washed with water and a saturated solution of sodium hydrogen carbonate (50 cm<sup>3</sup> each), dried (sodium sulfate), and evaporated under reduced pressure to leave a residue which was purified by flash chromatography (hexane-dichloromethane 3:2 for chloroacetate, R<sub>f</sub> = 0.35; hexane-dichloromethane 1:2 for alcohol, R<sub>f</sub> = 0.20) on silica gel to give (S)-chloroacetate (0.367 g, 44%, [α]<sup>20</sup><sub>D</sub> = 82.57 (c 2.57 in acetone), ee 98% and [α]<sup>20</sup><sub>D</sub> = +35.68 (c 2.04 in acetone) after chemical hydrolysis) as a liquid and (R)-alcohol (0.393 g, 43%, ee 98%; [α]<sup>20</sup><sub>D</sub> = +35.92 (c 1.96 in acetone) before crystallisation from petroleum ether (40-60°C)-dichloromethane, afterwards [α]<sup>20</sup><sub>D</sub> = +35.95 (c 2.05 in acetone); mp 48-49°C) as a crystalline solid.

Chemical hydrolysis of (S)-1-(4-iodophenyl)ethyl chloroacetate

(S)-Chloroacetate (0.340 g, 1.05 mmol) was dissolved in methanol/sodium methoxide (17 cm<sup>3</sup>, obtained by dissolving 69 mg of sodium in 30 cm<sup>3</sup> of dry methanol). After 1 hr, water (few drops) was added and solution was concentrated under reduced pressure. Water (30 cm<sup>3</sup>) and dichloromethane (15 cm<sup>3</sup>) were added. The organic layer was separated and the aqueous one was extracted with dichloromethane (2 x 15 cm<sup>3</sup>). The combined organic layers were dried (sodium sulfate) and evaporated to leave a residue, which was purified by flash chromatography (hexane-dichloromethane 1:2, R<sub>f</sub> = 0.17) to give (S)-alcohol (0.240 g, 92%, ee 98%) as a crystalline solid.

c. (R)-(+)-Methyl 3-[1-(4-iodophenyl)ethyl]-3H-imidazole-4-carboxylate

A solution of (S)-alcohol (1.98 g, 7.98 mmol, ee > 98%) in dry THF (14.5 cm<sup>3</sup>) was added dropwise to a stirred solution of methyl 3H-imidazole-4-carboxylate (1.008 g,

7.98 mmol) and triphenylphosphane (2.503 g, 9.43 mmol) in dry THF (22.0 cm<sup>3</sup>) in an atmosphere of argon -30°C. Then, a solution of di-*t*-butyl azodicarboxylate (2.204 g, 9.57 mmol) in dry THF (14.5 cm<sup>3</sup>) were added and the stirred reaction mixture was allowed to warm up from -30°C to 0°C within 2.5 hr. No alcohol could be detected by TLC (diethyl ether-diisopropylamine 10:1). The reaction mixture was concentrated under reduced pressure. The residue was mixed with diethyl ether (36 cm<sup>3</sup>) and stirred for 2 h. The crystals (triphenylphosphanoxide and hydrazo ester) were collected and washed with diethyl ether (3 x 15 cm<sup>3</sup>). The filtrate was evaporated under reduced pressure to leave a residue, which was purified by flash chromatography (hexanes-diethyl ether-diisopropylamine 50:30:1; TLC: diethyl ether-diisopropylamine 10:1, R<sub>f</sub> = 0.44 for iodide, 0.54 for metomidate) on silica gel to give *p*-iodometomidate (1.91 g, 67%, ee 99%); [α]<sup>20</sup><sub>D</sub> = +76.0 (c 1.09 in acetone).

Found: C, 43.8; H, 3.7; N, 7.9. C<sub>13</sub>H<sub>13</sub>IN<sub>2</sub>O<sub>2</sub> requires C, 43.7; H, 3.8; N, 7.7; ν<sub>max</sub> (Si, film)/cm<sup>-1</sup> 2981, 2947, 1712, 1487, 1437, 1363, 1220, 1134, 1111, 1006; δ<sub>H</sub>(400.13 MHz, CDCl<sub>3</sub>) 1.81 (3 H, d, J 7.5, CH<sub>3</sub>CH), 3.77 (3 H, s, OCH<sub>3</sub>), 6.26 (1 H, q, J 7.5, CH<sub>3</sub>CH), 6.88 (2 H, d, J 8.5, 2 x H<sub>arom</sub>), 7.63 (2 H, d, J 8.5, 2 x H<sub>arom</sub>), 7.73 (1H, s, H<sub>hetarom</sub>), 7.75 (1H, d, J 1.0, H<sub>hetarom</sub>); δ<sub>C</sub> (100.61 MHz, CDCl<sub>3</sub>) 22.09 (CH<sub>3</sub>CH), 51.47 (OCH<sub>3</sub>), 54.96 (CH<sub>3</sub>CH), 93.46 (IC<sub>arom</sub>), 122.29 (2 C, 2 x HC<sub>arom</sub>), 128.02 (2 C, 2 x HC<sub>arom</sub>), 137.94 (C<sub>arom</sub>), 138.40 (HC<sub>hetarom</sub>), 139.54 (HC<sub>hetarom</sub>), 141.10 (CCO), 160.58 (CO).

d. (R)-(+)-Methyl 3-[1-(4-trimethylstannylphenyl)ethyl]-3H-imidazole-4-carboxylate  
Hexamethylditin (0.645 g, 3.2 mmol, 6.5 cm<sup>3</sup> of a solution of 1.0 g hexamethylditin in 10 cm<sup>3</sup> of dry toluene), tetrakis(triphenylphosphane)palladium (58 mg, 5 mol%) and triethylamine (1.6 cm<sup>3</sup>, 11.6 mmol) were added to a stirred solution of iodometomidate (0.368 g, 1.03 mmol, ee >98%) in an atmosphere of argon and refluxed (bath temperature 135°C) for 17 hr. The cooled solution was concentrated under reduced pressure and the residue was purified by flash chromatography (hexane-diethyl ether-diisopropylamine 60:30:1; TLC: diethyl ether-diisopropylamine 10:1, R<sub>f</sub>=0.71 for stannane, R<sub>f</sub>=0.50 for iodometomidate) on silica gel to give stannane (0.377 g, 96%) as a crystalline solid (Found: C, 48.7; H, 5.6 N, 7.1, C<sub>16</sub>H<sub>22</sub>N<sub>2</sub>O<sub>2</sub>Sn requires C, 48.9; H, 5.6; N, 7.1%); mp 77-79°C (from hexane); [α]<sup>20</sup><sub>D</sub> = +82.09 (c 2.06 in acetone).



$\nu_{\max}$  (Si, film)/ $\text{cm}^{-1}$  2981, 1715, 1437, 1362, 1218, 1133, 1110, 1049;  $\delta_{\text{H}}$  (400.13 MHz,  $\text{CDCl}_3$ ) 0.25 (9 H, s,  $(\text{CH}_3)_3\text{Sn}$ ,  $^{117/119}\text{Sn}$  satellites, 2 x d, J 53.2 and 55.2), 1.82 (3 H, d, J 7.0,  $\text{CH}_3\text{CH}$ ), 3.77 (3 H, s,  $\text{OCH}_3$ ), 6.30 (1 H, q, J 7.0,  $\text{CH}_3\text{CH}$ ), 7.13 (2 H, d, J 8.0, 2 x  $\text{H}_{\text{arom}}$ ,  $^{117/119}\text{Sn}$  satellites, d, J 9.0), 7.43 (2 H, d, J 8.0, 2 x  $\text{H}_{\text{arom}}$ ,  $^{117/119}\text{Sn}$  satellites, d, J 42.7), 7.71 (1 H, s,  $\text{H}_{\text{hetarom}}$ ), 7.74 (1 H s,  $\text{H}_{\text{hetarom}}$ );  $\delta_{\text{C}}$  (100.61 MHz,  $\text{CDCl}_3$ ) -9.61 (3 C,  $(\text{CH}_3)_3\text{Sn}$ ), 22.16 ( $\text{CH}_3\text{CH}$ ), 51.40 ( $\text{OCH}_3$ ), 55.30 ( $\text{CH}_3\text{CH}$ ), 122.31 ( $\text{C}_{\text{arom}}$ ), 125.81 (2 x C, 2 x  $\text{HC}_{\text{arom}}$ ),  $^{117/119}\text{Sn}$  satellites, d, J 45.9), 136.28 (2 x C, 2 x  $\text{HC}_{\text{arom}}$ ,  $^{117/119}\text{Sn}$  satellites, d, J 36.8), 122.29 (2 C, 2 x  $\text{HC}_{\text{arom}}$ ), 128.02 (2 C, 2 x  $\text{HC}_{\text{arom}}$ ), 137.94 ( $\text{C}_{\text{arom}}$ ), 138.23 ( $\text{HC}_{\text{hetarom}}$ ), 139.84 ( $\text{HC}_{\text{hetarom}}$ ), 141.00 ( $\text{C}_{\text{arom}}$  or  $\text{CCO}$ ), 142.24 ( $\text{CCO}$  or  $\text{C}_{\text{arom}}$ ), 160.68 ( $\text{CO}$ ).

e. Preparation of (R)-(+)-Methyl 3-[1-(4-[ $^{131}\text{I}$ ]iodophenyl)ethyl]-3H-imidazole-4-carboxylate

30  $\mu\text{g}$  4-Stannan-MTO is reacted with [ $^{131}\text{I}$ ]iodide in 10 – 20  $\mu\text{l}$  NaOH (0.05N), 15  $\mu\text{l}$  chloramine-T (1 mg/ml, aqueous), 6  $\mu\text{l}$  hydrochloric acid (1 N) during 1 min at ambient temperature. The reaction is stopped with 6  $\mu\text{l}$  NaOH (1 N), to give the  $^{\text{I}}$  compound with a radiochemical yield: >95%, radiochemical purity: >99%, specific activity: 1MBq/nmol; chemical purity: >95%.

By following the preparation as described above for (R)-methyl 3-[1-(4-iodophenyl)ethyl]-3H-imidazole-4-carboxylate (4-iodo-MTO) further compounds according to the invention can be synthesized, such as e.g. (R)-ethyl 3-[1-(4-iodophenyl)ethyl]-3H-imidazole-4-carboxylate (4-iodo-ETO) and their radioactive analogues.

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